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Plant maturity and kenaf yield components

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Abstract

Kenaf (*Hibiscus cannabinus* L.), an alternative fiber crop for paper pulp production, is normally grown during the entire summer growing season (150 days and longer) to maximize fiber production. However, it may be advantageous to harvest the kenaf crop earlier than 150 days after planting (DAP) depending on the harvesting conditions (e.g. soil moisture or equipment availability) or marketing opportunities (price fluctuations or alternative uses). In addition to affecting the final stalk yield, harvesting kenaf at an earlier maturity may significantly alter the composition of the kenaf plant. The objective of this field study was to determine the effect of kenaf plant maturity on kenaf yield components. Kenaf cultivar 'Everglades 41' was planted at Lane, Oklahoma, USA, in the spring of 1996, 1997, and 1998 on 76 cm row spacing at 250 000 plants per hecatre. Kenaf plots were harvested at four harvest dates, 60, 90, 120, and 150 DAP. At each harvest date, plants from a 3 m length of row were cut at ground level and used to determine plant population, plant height, stalk, leaf and whole plant yields, stalk and leaf percentage by weight, and the rate of plant growth during the selected growing season. The experiment was a randomized complete block design with five replications. Harvest age (60, 90, 120, and 150 DAP) did not significantly affect plant populations, but significantly affected all other yield parameters. Kenaf plant height, stalk yield, stalk percentage, and total plant biomass yields were consistently significantly greater at 150 DAP than at 60, 90, and 120 DAP for the 3 year study. Although the growth rates per day did level off or even decreased after 120 DAP, the significant increases in stalk yields after 120 DAP justify the additional 30 day growth. This research provides information that can be applied to both kenaf fiber and forage production, especially in gaining a greater understanding of the relative response of the kenaf yield components and partitioning of dry matter during the growing season. The research procedures can also be used for evaluating kenaf cultivars that may be more suitable for forage production, by identifying cultivars that have greater leaf biomass yields and leaf percentages earlier in the season and increasing values throughout the growing season.

Keywords: Kenaf; *Hibiscus cannabinus* L.; Yield components; Biomass; Plant height; Harvest age

1. Introduction

For the last 3000 years, kenaf has been used as a cordage crop to produce twine, rope, and sackcloth (Wilson et al., 1965). Kenaf was first domes-

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ticated and used in northern Africa. India has produced and used kenaf for the past 200 years, whereas Russia started producing kenaf in 1902 and introduced the crop to China in 1935. In the US, kenaf research and production began during World War II to supply ropes for the war effort and developed high-yielding anthracnose-resistant varieties, cultural practices, and harvesting machinery (Nieschlag et al., 1960; Wilson et al., 1965; White et al., 1970). In the 1950s and early 1960s, USDA researchers determined that kenaf was an excellent source for cellulose fibers for a large range of paper products (newsprint, bond paper, and corrugated liner board) requiring less energy and chemical for processing than standard wood sources (Nieschlag et al., 1960; Clark and Wolff, 1962, 1965, 1969; White et al., 1970; Clark et al., 1971). The kenaf fibers, bast and core, can be pulped as a whole stalk or separated and pulped individually (Kaldor et al., 1990). More recent research and development work in the 1990s has demonstrated the plant's suitability for use in building materials (particle boards of various densities, thicknesses, and fire and insect resistance), adsorbents, textiles, livestock feed, and fibers in new and recycled plastics (injected molded and extruded) (Webber and Bledsoe, 1993; Webber et al., 1999).

Although kenaf is usually considered a fiber crop, the entire kenaf plant, stalk (core and bark) and leaves, can be used as a livestock feed. Research indicates that it has high protein content (Clark and Wolff, 1969; Killinger, 1969). Crude protein in kenaf leaves ranged from 14 to 34% (Killinger, 1969; Suriyajantratong et al., 1973; Swingle et al., 1978; Webber, 1993b), stalk crude protein ranged from 2 to 12% (Swingle et al., 1978; Webber, 1993b), and whole-plant crude protein ranged from 6 to 23% (Killinger, 1969; Swingle et al., 1978; Webber, 1993b). Kenaf can be ensilaged effectively, and it has satisfactory digestibility with a high percentage of digestible protein (Wing 1967). Digestibility of dry matter and crude proteins in kenaf feeds ranged from 53 to 58 and 59 to 71%, respectively, (Wing 1967 Suriyajantratong et al., 1973; Swingle et al., 1978). Kenaf meal, used as a supplement in a rice ration for sheep, compared favorably with a ration containing alfalfa meal (Suriyajantratong et al., 1973). Chopped kenaf (29% dry matter, 15.5% crude protein, and 25% acid detergent fiber) is also suitable feed source for Spanish (meat-type) goats (Wildeus et al., 1995).

Stalk yield differences compared within the same location (White et al., 1970), across different locations (White et al., 1970; Ching et al., 1993), or across different years within a location (Webber, 1993a) are influenced or probably influenced by differences in the length of kenaf growing season. The length of the growing season can also influence other yield components such as plant height (Ching et al., 1993; Webber, 1996) and total dry matter (Bhardwaj and Webber, 1994; Bhardwaj et al., 1995). The age of kenaf at harvest can influence plant composition, such as leaf and stalk percentages, and protein content (Webber, 1993b; Bhardwaj and Webber, 1994). Due to the increased number of uses for the kenaf plant, whether for industrial applications or for livestock feed, we need a better understanding on how the yield components (plant population, plant height, stalk and leaf yield, total biomass, and leaf and stalk percentages) are affected by plant age at harvest. The objective of this 3-year field study was to determine the effect of plant maturity at harvest (days after planting) on yield components important to both fiber and feed uses.

2. Material and methods

A field study was conducted three times over a 3 year period (1996, 1997, and 1998) at Lane, Oklahoma, USA (34°18′ N, 95°59′ W) on a Bernow fine sandy loam, 0–3% slope, (fine-loamy, siliceous, thermic Glossic Paleudalf). Prior to planting, fertilizer was applied at a rate of 168 kg ha^{-1} N, 72 kg ha^{-1} P, 139 kg ha^{-1} K. A field cultivator was used to incorporate the fertilizer and to prepare the seedbed for planting. All plots were kept weed-free by handweeding throughout the growing season.

Plots were 8 m long, and oriented in an east-west direction. Kenaf cultivar 'Everglades 41' was planted each year (30 April, 1996, 10 May, 1997, and 14 May, 1998) and hand-harvested 60, 90, 120 and 150 days after planting (DAP). 'Everglades 41' was developed by USDA researchers to extend the vegetative growing season before the plants initiate flowering (Wilson et al. 1965). The 1996 crop received moisture only from precipitation, whereas in 1997 and 1998, the crop was irrigated to provide moisture levels comparable with those of the 1996 growing season. Supplemental water was applied in 1997 and 1998 with drip irrigation (Table 1). The drip irrigation system consisted of a single 16 mm drip line for each plant row with in-line emitters spaced every 30 cm with an application rate of 2.4 l h^{-1} for each emitter. A 2.28 m^2 (0.76 by 3 m) area was harvested from the center rows. The harvested plants were cut at ground level and fresh weights were recorded. Leaves were removed from the stalks and were weighed separately, before and after the samples were oven-dried at 66 °C for 48 h. Fresh and oven-dry weights of the plants were used to determine the water content of the plants, and the percentage stalk and leaves by weight. Stalk and leaf yields were based on oven-dry weight. Plant counts from the harvest area were used to determine plant populations. Five plants from each harvested area were measured to determine the average plant height per plot.

Treatments were arranged in a randomized complete block design with five replications (Snedecor and Cochran, 1967). When the F-test indicated statistical significance at the $P = 0.05$ level, the least significant difference (LSD) test was used to separate means.

3. Results and discussion

3.1. Growth conditions

Precipitation during the 1996 growing season, from planting to harvest, was 820 mm, whereas precipitation and irrigation during the 1997 and 1998 growing seasons was 891 and 854 mm, respectively (Table 1) The 15 year average precipitation during the growing season for Lane, OK is 520 mm (Table 1).

The primary weeds present during all 3 years were tumble pigweed (*Amaranthus albus* L.) and large crabgrass (*Digitaria sanguinalis* (L.) Scop.). Both weed species were present at moderate populations and were removed throughout the growing season by handweeding.

3.2. Plant population

Plant population did not have a significant year by DAP interaction, maintaining the same relative response among DAP treatments during each year of the 3 year experiment. Plant populations were not significantly different among the DAP treatments averaged across the years or among years averaged across DAP treatments (Table 2). The plant populations for the DAP treatments averaged across years were 222 110 (60 DAP), 215 620 (90 DAP), 239 580 (120 DAP), and 241 750 plants Per hecatre (150 DAP) and the yearly plant populations averaged across DAP treatments were 219 790 (1996), 236 470 (1997), and 233 030 plants

Table 1
Precipitation and irrigation totals for each growing period during 1996, 1997, 1998, and the 15 year average precipitation (1985–1999) for Lane, OK

Growing period, (DAP)	Total water (mm) 1996[a]	1997[b]	1998[b]	15 Year average[a]
Planting to 60	133	233	187	260
61–90	152	146	148	68
91–120	261	244	243	69
121–150	274	268	276	123
Total (Planting to 150 DAP)	820	891	854	520

[a] Precipitation only, no irrigation water applied.
[b] Precipitation and irrigation during the growing season.

Table 2
Plant population, total biomass yield, stalk DBA, leaf DBA, and total biomass DBA averaged across years for 60, 90, 120, 150 days after planting (DAP) and averaged across DAP for 1996, 1997, and 1998

Harvest date (DAP)	Plant population (plants ha^{-1})	Total biomass Yield (kg ha^{-1})	Stalk DBA (kg ha^{-1} per day)	Leaf DBA (kg ha^{-1} per day)	Total biomass DBA (kg ha^{-1} per day)
60	222110 a[a]	5705 d	55.3 c	39.8 b	95.1 d
90	215620 a	11528 c	83.7 b	44.4 a	128.1 c
120	239580 a	18182 b	114.8 a	36.7 b	151.5 a
150	241750 a	21005 a	114.1 a	26.0 c	140.0 b
LSD (0.05)	30100 NS	929	6.8	4.3	9.3
(*Year*)					
1996	219790 a	14257 a	102.0 a	26.9 c	129.0 ab
1997	236470 a	14792 a	89.1 b	46.4 a	135.5 a
1998	233030 a	13265 b	84.7 b	36.9 b	121.6 b
LSD (0.05)	26070 NS	804	5.9	3.7	8.1

[a] Means within columns and within each subsection that are followed by a different letter are significantly different according to the LSD at 0.05 level. These yield components did not have a significant year by DAP interaction.

per ha (1998). These values were not significantly different from each other and well within the range of 99 000–395 000 plants per ha, reported by Higgins and White (1970) as not detrimental to final stalk yields. When comparing the effect of harvest age on kenaf yield components, it is important to be able to remove any confounding effects due to differences in plant populations. Higgins and White (1970) reported that too sparse plant populations resulted in a greater number of undesirable branching plants, whereas too dense populations produce smaller plants that were much more likely to lodge. Thus, Higgins and White (1970) recommended plant populations between 200 000 and 300 000 plants per ha.

3.3. Total biomass yields

The total biomass yields represent the combined oven-dried weights of all of the aboveground plant material (stalks and leaves). Since no significant year by DAP interaction for total biomass yields was present the data will be discussed in terms of the average across years and across DAP treatments (Table 2). Total biomass yields increased from 60 DAP (5705 kg ha^{-1}) to 150 DAP (21 005 kg ha^{-1}), with each harvest (60-, 90-, 120-, and 150-DAP) greater than the one preceding (Table 2). The trend of increasing total biomass yields is consistent with kenaf results at the same location, which evaluated the effect of three harvest dates (75 DAP, 98 DAP, and full season) on kenaf forage yield and quality (Webber, 1993b). The total biomass yields for 1996 (14 257 kg ha^{-1}) and 1997 (14 792 kg ha^{-1}) were significantly greater than for 1998 (13 265 kg ha^{-1}) when averaged across all DAP treatments. White et al. (1970) and Webber (2000) reported that higher average air temperatures, longer growing seasons, and adequate soil moisture are three major factors that promote the greatest yields among locations and between years. In this research, the length of the growing season was a treatment factor kept constant across years, and the soil moisture was fairly consistent across years. The planting date for the 1998 crop was planted 14 days later than the 1996 crop and 4 days later than the 1997 crop. White et al. (1970) reported that ‘yields will be reduced more often as a result of late planting than of early planting’. Therefore, the lower biomass yields in 1998 may be the result of differences in the average air temperatures among the growing seasons combined with a slightly later planting date.

3.4. Stalk and leaf biomass yields within years

As a result of significant year by DAP interactions for stalk and leaf biomass yields, this data set will be discussed within years (Table 3). Stalk biomass yields were significantly different among DAP and increased from 60 to 150 DAP during each year, following the same trend as total biomass yields within years (Table 3). The trend of increasing stalk yields with the length of growing period is consistent with White et al. (1970) who, although reporting on growing periods of 150 and 180 DAP for fiber production, did report that stalk yields increased with the length of the growing period for the eight cultivars tested, including Everglades 41. In contrast, leaf biomass yields varied among years in the response to DAP and did not increase with each subsequent harvest date (Table 3). Although leaf biomass yields were always the lowest at the 60 DAP harvest, the yields during the 90-, 120-, and 150 DAP harvests were often not significantly different from each other. Within each year, leaf yields for the final harvest (150 DAP) were not significantly greater than either the 90 or 120 DAP harvests. The less than maximum leaf biomass yields at the 150 DAP harvest was not the result of the absence of leaf growth during the last 30 days of growth (120–150 DAP), but rather because the rate of leaf abscission was greater than new leaf growth (Clark and Wolff, 1969; Webber, 1993b). As the kenaf plant increases in height and maturity, the lower leaves senesce, often producing plants at harvest (e.g. 150 DAP) without leaves on the lower one-half to three-quarters of the plant stalk.

3.5. Stalk and leaf percentages

Stalk and leaf percentage represents the percentage by weight (oven-dried) of stalk or leaf biomass compared with the total above ground plant material (stalks and leaves). These biomass percentages maintained an inverse relationship to each other (Table 3). As the stalk biomass percentage increased from 60 to 150 DAP, the leaf biomass values decreased. Within each year, the percentage of stalk biomass increased significantly (leaf biomass decreased) with each harvest date (60-, 90-, 120-, and 150-DAP) (Table 3). Also within years, the greater the stalk yield, the greater the stalk biomass percentage (Table 3). The stalk yields and stalk percentages are important for fiber production because the stalks are the source of the bark (bast) and core fibers. The leaf percentages are related to livestock feed because the leaves are the primary source of protein (Webber, 1993b). After incorporating disease resistance or disease tolerance into potential kenaf cultivars, geneticists have used both stalk yields and stalk/leaf biomass percentages for selecting and releasing suitable plant cultivars (Wilson et al., 1965). Wilson et al. (1965) reported that of the two new anthracnose-resistant cultivars released in 1965, Everglades 71 was selected because of its superior stalk yields, whereas Everglades 41 was released 'primarily for its adaptability to mechanical harvesting' (self-defoliating habit resulting in lower leaf biomass percentages and even-sized stalks). The leaf and stalk yields and biomass percentages are important factors in selecting cultivars to be used for kenaf fiber and forage production. The majority of the breeding programs in the US have developed cultivars that are more suitable for fiber production (stalk yield, self-defoliating, greater stalk percentages, reduced branching) than for forage production.

3.6. Plant height and plant height growth rate

In all 3 years, plant height also increased with each succeeding harvest date from 60 to 150 DAP (Table 3). As the plant height increased within years, the stalk biomass yields and the stalk biomass percentages also increased. These results are consistent with Ching et al. (1993) who reported the same trend with full season kenaf for fiber production. The plant height growth rate, the plant height from planting to harvested divided by the number of days in the growing season (e.g. 60-, 90-, 120-, and 150 days), varied among years. In 1996, the rate of increase peaked at the 90 DAP harvest and decreased at the 150 DAP harvest. Although not always significantly different, the 1997 and 1998 plant height growth rate produced a trend of decreased growth from the 60 to the 120 DAP harvest and then increased for the final 150 DAP.

Table 3
Yield components (stalk yield, stalk growth rate, percent stalk biomass, plant height, and plant height growth rate for 1996, 1997, and 1998 at 60, 90, 120, 150 days after planting (DAP)

Year	Harvest date	Stalk yield (kg ha^{-1})	Leaf yield (kg ha^{-1})	Total yield (kg ha^{-1})	Stalk biomass (%)	Leaf biomass (%)	Plant height (cm)	Height growth rate (cm per day)
1996	60 DAP	3781 d[a]	1817 c	5599 d	68 d	32 a	145 d	2.41 c
	90 DAP	7816 c	3182 a	10999 c	71 c	29 b	241 c	2.68 b
	120 DAP	15564 b	2889 ab	18453 b	84 b	16 c	353 b	2.94 a
	150 DAP	19286 a	2692 b	21979 a	88 a	12 d	402 a	2.68 b
	LSD (0.05)	1367	385	1533	1.8	1.8	12.6	0.109
1997	60 DAP	3119 d	2989 c	6108 d	51 d	49 a	118 d	1.96 ab
	90 DAP	7708 c	4643 b	12351 c	62 c	38 b	169 c	1.88 b
	120 DAP	13162 b	5796 a	18959 b	69 b	31 c	206 b	1.72 c
	150 DAP	16387 a	5364 ab	21752 a	75 a	25 d	308 a	2.06 a
	LSD (0.05)	1431	817	1863	3.0	3.0	13.7	0.134
1998	60 DAP	3048 d	2360 b	5408 d	57 d	43 a	108 d	1.80 b
	90 DAP	7065 c	4169 a	11234 c	63 c	37 b	157 c	1.74 b
	120 DAP	12608 b	4526 a	17134 b	73 b	27 c	202 b	1.68 b
	150 DAP	15650 a	3634 a	9283 a	81 a	19 d	299 a	1.99 a
	LSD (0.05)	1619	938	1773	4.2	4.2	18.3	0.161

[a] Means within columns and within each subsection that are followed by a different letter are significantly different according to the LSD at 0.05 level.

3.7. Daily biomass accumulation

The daily biomass accumulation (DBA) was determined by dividing the stalk, leaf, and total biomass yield for each growing period by the number of days in that same growing period. The stalk, leaf, and total DBA did not have a significant year by DAP interaction, maintaining the same relative response among DAP treatments each year. When averaged across years, the stalk DBA increased with each succeeding harvest date from 60 DAP (55.3 kg ha^{-1} per day), to 90 DAP (83.7 kg ha^{-1} per day), and to 120 DAP (114.8 kg ha^{-1} per day; Table 2). From 120 to 150 DAP, the stalk DBA did not change significantly, 114.8 and 114.1 kg ha^{-1} per day, respectively. The total biomass DBA followed the initial trend of the stalk DBA, increasing from 60 DAP (95.1 kg ha^{-1} per day) to 90 DAP (128.1 kg ha^{-1} per day), but unlike the stalk DBA the rate of growth for total biomass was greater for 120 DAP (151.5 kg ha^{-1} per day) than for the 150 DAP (140.0 kg ha^{-1} per day). The difference in the response of the stalk and total DBA during the 120 and 150 DAP growing periods was influenced by inclusion of the decreasing leaf DBA (Table 2) and leaf percentages (Table 3) for 150 DAP.

4. Conclusions

Total biomass yields increased from 60 DAP to 150 DAP, with each harvest greater than the preceding harvest. Stalk biomass yields were significantly different among DAP and increased from 60 to 150 DAP during each year, following the same trend as total biomass yields within years. In contrast, leaf biomass yields varied among years in the response to DAP and did not increase with each subsequent harvest date. The stalk and leaf biomass percentages maintained an inverse relationship. As the stalk biomass percentage increased from 60 to 150 DAP, the leaf biomass values decreased. Within each year, the percentage of stalk biomass increased significantly (leaf biomass decreased) with each harvest date. Within years, the greater the stalk yield, the greater the stalk biomass percentage. In all 3 years, plant height also increased with each succeeding harvest date 60 to 150 DAP. The stalk biomass yields and the stalk biomass percentages also increased as the plant height increased within years. The growth rate data (stalk and leaf biomass, and plant height) showed differences among years, but consistently indicated that the plant growth rates peaked prior to the last growing period. Information has been developed that can be applied to both kenaf fiber and forage production, especially in gaining a better understanding of the relative response of the kenaf yield components and partitioning of dry matter during the growing season. The approach can also be used for the evaluating of kenaf cultivars that may be suitable for forage production, by identifying cultivars that have greater leaf biomass yields and leaf percentages earlier in the season and increasing throughout the growing season.

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